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Sectoral labour reallocation: An agent-based model of structural change and growth☆,☆

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Abstract

The shift of labour out of the agricultural sector and into the manufacturing and services sectors seems to be an important factor in explaining why some countries are so much richer than others. Therefore, understanding not only the driving mechanisms and forces behind the process of structural change but also how these mechanisms interact and reinforce each other becomes crucial. In the present work, we develop an agent-based model (ABM) where structural change is driven by income and relative prices effect. The income effect is generated by the assumption of a simple non-homothetic hierarchical demand structure where consumers spend their wealth following a particular priority ordering. The relative prices effect results from different sectoral productivity growth rates. The model is capable of theoretically replicating the dynamics of structural change where labour is reallocated across the three macro-sectors of agriculture, manufacturing and services. We have calibrated the model's parameters, so that the artificial employment share trajectories would match those of Sweden for the period of 1890–2010. The results suggest that, the income and relative prices effect are complementary in generating a process of structural change of the type experienced by developed economies. If some assumptions regarding agents' behaviour and sectoral relative conditions are respected, the model shows that it possible to theoretically yield structural changes in an agent-based model focusing only on first principles such as tastes and technologies.

JEL classification: O00; O41; L16

Keywords: Agent-based model; Structural change; Growth; Income effect; Relative-price effect

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1. Introduction

One of the most complex questions in all of economic theory is why some countries are so much richer than others. This question is particularly challenging as the factors that make a country rich may vary not only across countries but also within countries across time. Factors and conditions that once benefited a particular nation's development might neither be present or effective at a different time nor have the same effect on different economies. There is a consensus that the large heterogeneity that we see today in countries' income per capita is the result of a combination of endogenous and exogenous factors.

In his Nobel lecture, Simon Kuznets summarized six characteristics of modern economic growth that emerged from his analysis based on conventional measures of national product and its components: population, labour force, and the like. The third of his six characteristics states that:

> "The rate of structural transformation of the economy is high. Major aspects of structural change include the shift away from agriculture to non-agriculture pursuits, and, recently, away from industry to services; a change of the scale of productive units, and a related shift from personal enterprise to impersonal organization of economic firms, with a corresponding change in the occupational status of labor." (Kuznets, 1973, p. 248)

Simon Kuznets was among the first economists to empirically describe the process of structural change. Some of the early empirical studies are Fischer (1939), Clark (1940), Kuznets (1957), Chenery (1960). Since then, much effort has been done in order to reconstruct historical data and provide a more comprehensive picture of this process. Important contributions were made by Maddison (1987), Syrquin (1988), Kaelble (1997), Dennis and İşcan (2009), Buera and Kaboski (2012), Broadberry et al. (2013) and Herrendorf et al. (2014) and many others.[1]

Structural change can be defined as the reallocation of labour and other resources across the agriculture, manufacturing, and services sectors. A broader definition, however, would also encompass the changes in the structure of production and employment within and between all sectors[2] of the economy as well as the emergence of new sectors and the disappearance of old ones (Gabardo et al., 2017). The decline in the share of employment in the agricultural sector and the process of industrialization have dramatically transformed the economic landscape in today's developed nations. These processes have not only changed the size and share of sectors in those economies, but also the size of their cities and ultimately their people's way of life.

Looking at the data, it is possible to identify some common economic features among poor countries and among rich countries. Regarding the common features of poor countries, Caselli (2005) observes that they have a much lower labour productivity in agriculture, a somewhat lower labour productivity outside agriculture, and a larger share of employment in the sector that – on average – is less productive. Among the common features of rich countries, in spite of the many idiosyncrasies in trends among them, there is a large body of evidence showing that structural change in these countries is characterized by a systematic fall in the share of labour allocated to agriculture over time, by a steady increase in the share of labour in services, and by a hump-shaped pattern for the share of labour in manufacturing (Gabardo et al., 2017). This pattern shows that, rich countries went first trough a period of industrialization as labour shifts from agriculture to manufacturing, followed by a period of de-industrialization as labour shifts from manufacturing to services.

According to Herrendorf et al. (2014), there is an association between increases in GDP per capita with declines in the employment share of agriculture, and corresponding rises in those of services. As a country develops, the relative contribution of agriculture to both total employment and GDP declines, the contribution of services rises in both respects and the contribution of manufacturing first expands and then contracts following a hump shape (Herrendorf et al., 2014). This pattern of sectoral labour reallocation can be seen in Fig. 1, that plots the sectoral employment shares for selected countries.

The evidence presented by Herrendorf et al. (2014) indicates that, most of today's high income countries went trough a dramatical shift in sectoral employment. There are basically two reasons that make economists believe that

[1] The list of contributions is too large for it to be included in its entirety.

[2] In the literature, a sector is often equivalent to an industry. Thus, it is possible to say that the manufacturing sector is composed of several manufacturing industries. As in Herrendorf et al. (2014), we use the term manufacturing to refer to activities neither classified as agriculture nor as service.

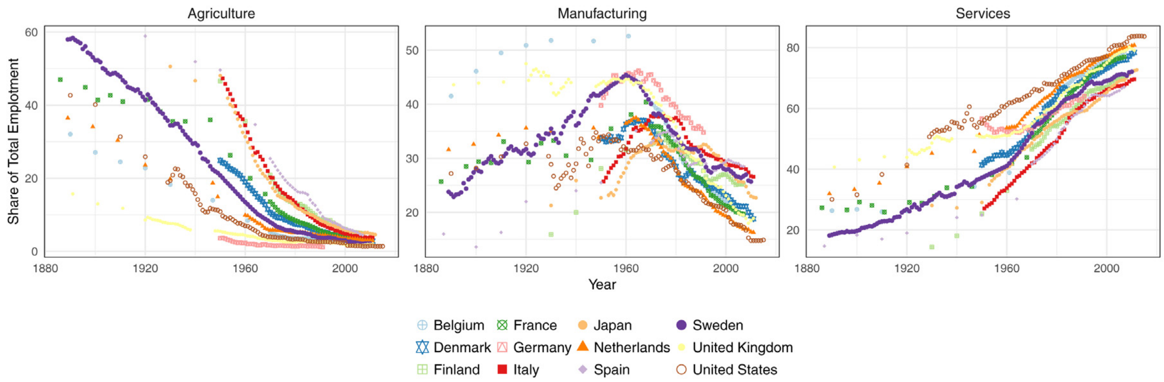

Fig. 1. Shares of total employment for selected countries between 1884 and 2015. Data source: Herrendorf et al. (2014) and Bolt and van Zanden (2014).

this pattern of labour reallocation out of agriculture and into manufacturing and services, although not sufficient, is a necessary condition of the process of growth. First, per capita demand for agricultural goods is relatively price and income inelastic at high levels of income. Second, the presence of a dominant fixed factor in agricultural production (land) limits the ability of the agricultural sector to absorb labour in the face of growing population levels (Foster and Rosenzweig, 2007). Therefore, understanding the causes not only of the labour reallocation out of agriculture but also out of the manufacturing and into the services is of great importance in order to explain why some countries are so much richer than others.

1.1. *The sources of structural change*

Despite its prominence and substantial empirical macroeconomic literature, in a theoretical perspective the study of structural change has been given less attention than that of economic growth. Only in the last decades that the subject of structural change has gained more prominence and has become a relevant research area.[3] The existing literature has advanced several explanations to account for the process of structural change experienced by developed countries. Here we present three channels or explanations (Dennis and İşcan, 2009, p. 187):

1. A version of Engel's Law operating on employment shares: as incomes rise, agriculture sheds labour due to the low income elasticity of demand for farm goods;
2. A version of Baumol's (1967) "cost disease": relatively faster productivity growth in agriculture pushes farm workers to produce complementary non-farm goods;
3. Different factor intensities in production: agricultural production is more conducive to rapid capital deepening, which in turn pulls labour into the more labour intensive non-farm sector.

These three explanations or channels seek to account for the process of structural change by means of different mechanisms. The first explanation is based on demand factors, while the second and third are based on supply factors. The first channel, also called the income or utility-based explanation, relies on differences in income elasticities of demand across sectors. This explanation goes back to Fisher (1935) and Clark (1940), who applied Engel's law to the demand for manufacturing goods.

Proponents of the utility-based explanation, have suggested that if one assumes non-unitary expenditure elasticities of demand (non-homothetic preferences), changes in income lead to changes in expenditure shares and to labour reallocation across sectors even if relative prices are constant. The utility-based explanation is consistent with Engel's

[3] Krüger (2008), Matsuyama (2008), Silva and Teixeira (2008) and Gabardo et al. (2017) review the literature on structural structural change.

law,[4] which is not only valid for basic or necessity goods but is a more general law of consumption.[5] Many authors rely on this channel to explain the process of structural change, including Matsuyama (1992), Echevarria (1997), Laitner (2000), Kongsamut et al. (2001), Gollin et al. (2002) and Foellmi and Zweimüeller (2008).

The second and third channels rely on changes in relative prices. These changes affect sectoral expenditure and employment shares whenever the elasticity of substitution across sectors is different from one. In the second channel, relative prices change as a result of differential productivity growth across sectors. This explanation goes back to Baumol (1967) and was formalized by Ngai and Pissarides (2007), which assert that structural change results from differences in the rates of total factor productivity across sectors. These differences cause changes in relative prices which induce the reallocation of labour across sectors.

In the third channel, relative prices change as a result of changes in the relative prices and supply of inputs if sectors factor's intensities in production are different. In this case, one can generate structural transformation via relative prices change even if technological change is neutral (Herrendorf et al., 2014). This last mechanism is found for instance in Caselli and Coleman (2001) and Acemoglu and Guerrieri (2008). In Caselli and Coleman (2001), skilled and unskilled workers are the two inputs of interest, while in Acemoglu and Guerrieri (2008) the two inputs are capital and labour. The former argue that as a result of a decrease in the cost of education in the first half of the 20th century, there was an increase in the relative supply of skilled workers which decreased the relative price of non-agricultural goods, and moved resources out of agriculture. The later allows for differences in sectoral capital intensities. The authors show that an increase in the capital-to-labour ratio leads to differential capital deepening across sectors.

Despite the fact that the mainstream literature has restricted its attention to either the supply or the demand side explanations of structural change, Boppart (2014) provides empirical evidence that both drivers, the income and the relative prices effect are relevant. By combining non-homothetic preferences and differential TFP growth rates, he is able to develop one explanation of how the process of structural change can be driven by income and the relative prices effect simultaneously. Since both explanations describe the same phenomenon, their integration, despite being a natural step, is a theoretical challenge for analytical models.

Notwithstanding the recent contributions, the microeconomic foundations of the transition from an agriculture-based economy to a diversified industrial and to a services-based economy are still poorly understood. The process of structural change is a complex phenomenon. Its understanding demands not only the analysis of the microeconomic behaviour of firms and consumers but also the analysis of the interaction between demand and supply forces that generate sectoral reallocation of resources.

In a comprehensive review of the subject, Krüger (2008) observes that in all the theories that he reviewed, technological progress drives structural change, but it is frequently the demand side that is crucial for determining which industries grow faster than others and which shrink, and it therefore shapes the direction of structural change. Moreover, Krüger (2008) continues and points out that further research, particularly on the feedback effects between structural change and aggregate growth, deserves much more attention. He suggests that the theoretical explanation of these issues almost surely requires other means of analysis than used so far and concludes arguing that agent-based computational models analysed by simulation methods might be an alternative (Krüger, 2008, p. 357).

In the present work, we make use of the, fairly new methodology of agent based models (ABM), to study the relation between two of the driving mechanisms of the process of structural change presented above. Agent based models that integrate growth and structural change are fairly recent in the literature, some examples are Lorentz and Savona (2008), Ciarli et al. (2010), Ciarli and Lorentz (2010), Ciarli et al. (2012), Lorentz et al. (2016), Ciarli and Valente (2016). Through the use of agent based models, it is possible to determine how individual decisions give rise to patterns, how these patterns in turn affect individual behaviour, and the dynamics that emerge from this interaction at the macro level. Agent-based models allow for a dynamical, more realistic and evolutionary representation of the economic system (Gräbner, 2016), therefore being suitable to exploring the dynamics of growth and structural change.

[4] In his famous 1857 article, Ernest Engel produced empirical evidence showing that the poorer a family is, the larger the budget share it spends on nourishment. This empirical regularity is known as Engel's law. Ernest Engel's analysis initially suggested that as income rises, the proportion of income spent on food falls, even if actual expenditure on food rises. Moreover, he argued that such a change in the composition of demand implies that, as the economy grows and per capita income increases, new resources can be dedicated to the production of other goods unrelated to food (Engel, 1857, p. 50). The relation that describe how expenditure on a particular good or service depends on income is called Engel curve.

[5] Deaton and Muellbauer (1980) concluded that the vast majority of studies obtains the result that the expenditure share of a product changes systematically with income.

We have developed an ABM where structural change is driven by income and the relative prices effects. The income effect is generate by the assumption of a simple non-homothetic hierarchical demand where consumers spend their income according to given priorities as in Falkinger (1990, 1994) and Andersen (2001). The relative prices effect results from different rates of sectoral productivity growth.

We seek to contribute to the literature by theoretically showing the possibility that two of the proposed explanations of structural change in the literature are complementary in replicating the patterns of employment reallocation experienced by developed economies.

The model developed here has many limitations and simplifying assumption that will be presented later. We do not claim that the two drivers explored in this work, the income effect and the relative prices effect, are the only or the most important sources of structural change. To see more on the mechanisms that can lead to structural change refer to Dennis and İşcan (2009), Gräbner (2016), Gabardo et al. (2017).

The remaining of the article is organized as follows: Section 2 briefly presents the model with its time-line of events. Section 3 presents a detailed account of the behaviour of the agents. Section 4 explains the simulation procedures and reports the results. Finally, Section 5 presents our concluding remarks.

2. The model (introduction)

We have built an agent-based model where agents are boundedly rational and follow simple rules of behaviour in an incomplete and asymmetric information context. The model simulates a closed economy with no government and no financial sector. The economy described by the model is composed of the following elements:

- A collection of 3 consumption sectors $z \in [1:3]$ namely agriculture = 1, manufacturing = 2 and services = 3;
- A collection of firms distributed across the z sectors. Firms use labour as the only input and within each sector, produce a homogeneous consumption good that satisfies one consumer need;
- A fixed collection of n^h individuals/workers with homogeneous and fixed skill level. Workers sell their labour force in exchange of a salary.

Since the main objective of our analysis is the transition of labour across sectors, we have decided to model a pure labour economy. Although the absence of physical capital may at first seem strange, one needs to be aware that most “growth” models that give rise to sustained growth are either based on endogenously determined accumulation of knowledge or exogenously given technological change. Frequently, models built around the accumulation of physical capital are not capable of generating sustained growth. The present model focuses on the endogenous accumulation of knowledge by the firms through in house R&D. As firms discover new production techniques, productivity and income-per-capita increase.

Given that, all firms in all sectors begin the simulation with the same amount of labour, in order to start the economy with different sectoral employment shares, the initial number of firms is different across sectors. All firms initiate with the same productivity level and the same financial endowment π_0^{acc}. The initial financial endowment is used to hire workers and pay wages in the first simulation period. Throughout the simulation, firms may increase or decrease their reserves depending on how much profit or loss they realize. Financial constraint can limit the firms’ ability to increase their workforce. The model assumes the possibility that new firms are created through a process of fission (see Section 3.1.6).

On the supply side, firm output is determined by variations on the quantity of labour employed, the technology available, consumers satiation and income and by the level of inventories. Firms devote a portion of their workforce exclusively to carry out R&D. Technological progress is endogenous and based on a stochastic process, that when successful, increases the firm’s productivity level.[6] On the demand side, in each period t, consumers observe the prices charged by a random subset of k[7] firms within each sector.

[6] In order to keep the model simple, we chose to focus exclusively on productivity increase. However, we acknowledge the vast literature that shows that the introduction of new consumer products is a necessary condition for economic progress in a market economy, Andersen (2001), Aoki and Yoshikawa (2002), Saviotti (2001), Saviotti and Pyka (2008), Foellmi and Zweimüeller (2008).

[7] This parameter reflects the degree of imperfect information on the consumers’ side.

The relative prices effect is generated through a specific parametrization that produces different productivity growth possibilities across sectors. The income effect is generated through a simple non-homothetic hierarchical demand structure. In the baseline parametrisation, consumption follows a hierarchical order, starting with agriculture, followed by manufacturing and ending with services. This hierarchical order establishes that all consumers must consume good 1 (agriculture), good 2 (manufacturing) and good 3 (services) in this specific order. In addition to hierarchical order, demand is bound by a satisfying quantity of each good (satiation level) that increases at different rates across sectors with increases in salary.

In order to study the dynamics of the income and the relative prices effect, we have modelled and simulated 4 (four) scenarios (Baseline, Case 2, Case 3 and Case 4) with different parametrization:

1. The baseline scenario assumes the presence of both effects, the income and the relative prices;
2. Case 2 eliminates the income effect. In this case, the hierarchical consumption order is abandoned and the satiation level increases at the same rate across sectors;
3. Case 3 eliminates the relative prices effect. In this case, all firms in all sectors have the same productivity growth possibilities;
4. Case 4 eliminates both effects, the relative prices and the income.

The main objective of simulating different scenarios is to analyse the impact of the income effect and of the relative prices effect on the trajectory of sectoral employment share. The hypothesis is that, the two explanations of structural change analysed here are complementary in replicating the sectoral employment shifts experienced by developed economies.

In the following subsections we firstly describe the sequence of events that takes place at each time step. Subsequently, we explain the firms and consumers' behaviour in greater detail.

2.1. *Time-line of events*

In each period of the simulation, the following sequence of events takes place:

1. *Firms' expected demand*: firms compute their expected demand based on past sales and past expected demand;
2. *Production planning*: given their inventory and expected demand, firms determine expected production level;
3. *Firms' labour demand*: firms calculate labour demand for production and for research;
4. *Labour market*: workers interact with firms in the labour market. Firms hire or dismiss labour depending on their labour requirements and financial situation;
5. *Production*: firms produce output;
6. *Wages and salaries*: the wage rate is calculated and firms pay salaries;
7. *Satiation point*: individuals calculate their satiation point for each of the three goods/sectors;
8. *Wealth and price search*: individuals calculate their available wealth for consumption and select a subset of firms from each sector to compare prices and visit;
9. *Consumption*: individuals and firms interact in the goods market;
10. *Profits and inventories*: firms calculate current profits/losses, inventories and accumulated profits;
11. *Consumer savings*: Consumers calculate individual savings;
12. *Aggregate Variables*: sector and economy level variables are computed.

3. Agent behaviours

This section details the behaviour of each type of agent.

3.1. Firm behaviour

3.1.1. Expected sales and expected production

Each period t starts with firms calculating their expected sales $s^e_{i,t}$ and expected production $x^e_{i,t}$. Expected sales are computed according to an adaptive scheme given by:

$$s^e_{i,t} = s^e_{i,t-1} + \omega(s_{i,t-1} - s^e_{i,t-1}) \tag{1}$$

where ω is an adaptive expectations parameter and $s_{i,t-1}$ is the firm i sales (in units) in the previous period.

Firm i expected production in period t depends on the its expected sales $s^e_{i,t}$ and on the amount of additional (extra) output that it wishes to supply in period t. We assume that all firms want to supply an extra share β of expected sales, as a buffer against unexpected demand swings (Steindl, 1952) and to supply constraints that may lead to consumer frustration (Lavoie, 1992).[8] Therefore, expected production is given by:

$$x^e_{i,t} = (1+\beta)s^e_{i,t} - inv_{z,i,t} \tag{2}$$

where $inv_{z,i,t}$ is the firm's inventory, calculated according to:

$$inv_{z,i,t} = \begin{cases} x^s_{i,t-1} - s_{i,t-1} & \text{if} \quad z = 1, 2 \\ 0 & \text{if} \quad z = 3, \end{cases} \tag{3}$$

where $x^s_{i,t-1}$ is the firm's past period total supply of goods, calculated as the sum of past actual production $x_{i,t-1}$ and past inventories, that is: $x^s_{i,t-1} = x_{i,t-1} + inv_{z,i,t-1}$.

3.1.2. Labour demand and production

Based on expected production $x^e_{i,t}$ and current productivity $a_{i,t-1}$, firms determine how many hours of labour for production they need. Expected labour hours for production is give by: $l^{ex}_{i,t} = \frac{a_{i,t-1}}{x^e_{i,t}}$.

In addition to labour for production, firms also demand labour for research. In the mainstream literature, authors such as Aghion and Howitt (1992) and Romer (1994) point that the amount of labour time spent in pursuing R&D is of great importance. According to them, there is a trade-off between production today, which can be increased through more labour time to production and less to R&D, and production tomorrow, which can be increased through more labour time devoted to R&D and less to production today. In the model, the expected amount of labour to R&D is calculated as a variable share of $l^{ex}_{i,t}$ according to:

$$l^{ers}_{i,t} = rds_{i,t-1} l^{ex}_{i,t} \tag{4}$$

where the share of labour dedicated to research $rds_{i,t}$ depends on the firm's market share and on the parameter γ, which is the maximum share of labour dedicated to R&D:

$$rds_{i,t} = (1 - ms_{i,t-1})\gamma \tag{5}$$

The firms' market share $ms_{i,t}$ is calculated as sales (units) over total sector sales (units): $ms_{i,t} = \frac{s_{i,t}}{S_{z,t}}$. When firms gain market share, they devote a lower percentage of labour to R&D. Total expected labour demand is given by: $l^e_{i,t} = l^{ex}_{i,t} + l^{ers}_{i,t}$.

As a simplifying assumption, there is no wage nor skill differentiation between production or research workers.

Although firms calculate their labour demand in terms of hours of labour, in the labour market they have to think in terms of workers.[9] Firms start each period with $wf_{i,t-1}$ workers. Throughout period t, they have the opportunity to increase or decrease their workforce. As the model does not have any kind of labour legislation, in order to emulate the rigidity effect of such a legislation on the labour market, we introduced a limit on the number of workers a firm can dismiss at a single period t. The limit is given by $wf_{i,t-1}\delta$, where $\delta \in [0:1]$ is a parameter that represents the labour

[8] In sectors $z = \{1, 2\}$ the share β is seen as a minimum inventory share, whereas for sector $z = \{3\}$, which supplies services not storable goods, the share β is simply a buffer against unexpected demand swings.

[9] We refer to as "labour force", $l_{i,t}$, the number of hours of labour and as "workforce", $wf_{i,t}$, the number of workers. As each worker accounts for wj labour hours, we have that $l_{i,t} = wf_{i,t} wj$.

market flexibility. The exception to this limit is when the firm is constrained by its financial situation, that is when $\frac{\pi^{acc}_{i,t-1}}{w_{t-1}wj} < wf_{i,t-1}(1-\delta)$. We can represent a firm's expected workforce for period t as:

$$wf^{e}_{i,t} = \max\left[\min\left[\frac{l^{e}_{i,t}}{wj}, \frac{\pi^{ac}_{i,t-1}}{w_{t-1}wj}\right], wf_{i,t-1}(1-\delta)\right] \tag{6}$$

where wj is the working journey, $\pi^{ac}_{i,t-1}$ is the firm's financial resources and w_{t-1} is the current wage rate (hourly) in the economy (see Section 3.1.3 for the determination of w_{t-1}).

The expected workforce can be greater or less than the initial period workforce $wf_{i,t-1}$. The firm will seek to hire workers if $wf^{e}_{i,t} > wf_{i,t-1}$ and fire if $wf^{e}_{i,t} < wf_{i,t-1}$. Altogether, a firm's workforce depends on the following factors: expected labour demand, accumulated profits, total labour availability, the working journey and the nominal wage. It might be the case that a firm wishes to increase its workforce, but it is unable to due to insufficient financial means or worker shortage.

The workforce demand $d^{wf}_{i,t}$, that is the number of workers that a firm wishes to add or subtract from its initial workforce $wf_{i,t-1}$, can be positive or negative according to:

$$d^{wf}_{i,t} = \begin{cases} \min\left[-(wf^{e}_{i,t-1} - wf_{i,t-1}), wf_{i,t-1}\delta\right] & \text{if } wf^{e}_{i,t} < wf_{i,t-1} \text{ and } \frac{\pi^{acc}_{i,t-1}}{w_{t-1}wj} > wf_{i,t-1}(1-\delta) \quad (7a) \\ \frac{\pi^{acc}_{i,t-1}}{w_{t-1}wj} - wf_{i,t-1} & \text{if } wf^{e}_{i,t} < wf_{i,t-1} \text{ and } \frac{\pi^{acc}_{i,t-1}}{w_{t-1}wj} < wf_{i,t-1}(1-\delta) \quad (7b) \\ wf^{e}_{i,t} - wf_{i,t-1} & \text{if } wf^{e}_{i,t} > wf_{i,t-1}, \quad (7c) \end{cases}$$

In Eqs. (7a) and (7b) the firm wishes to reduce its workforce ($d^{wf}_{i,t} < 0$), while in Eq. (7c) it wants to increase its workforce ($d^{wf}_{i,t} > 0$). The workforce demand is always rounded to the closest integer. Regarding the execution order, the simulation determines that the firing process occurs first. That is, all firms that want to reduce their workforce, have to do so before any firm can hire any worker.

Since the supply of workers is fixed and all firms pay the same wage rate, a random process of firm-worker matching is carried out. This process is done is cycles. In each cycle, each firm is randomly selected and allowed to hire 1 (one) worker. The cycles continue until all firms have hired the number of workers they desire, or there are no more workers to be hired.

In case that, at the end of the cycles, a firm's actual workforce turned out to be lower than its expected workforce, that is $wf_{i,t} < wf^{e}_{i,t}$, the firm devotes $l^{rs}_{i,t} = (wf_{i,t})(rds_{i,t})wj$ hours of labour to R&D and $l^{x}_{i,t} = (wf_{i,t})wj - l^{rs}_{i,t}$ hours of labour to production, so that the total actual labour force is: $l_{i,t} = l^{rs}_{i,t} + l^{x}_{i,t}$.

After adjusting their labour force, firms carry out production. Actual production is given by:

$$x_{i,t} = \min[x^{e}_{i,t}, x^{\max}_{i,t}] \tag{8}$$

where $x^{\max}_{i,t} = a_{i,t-1}l^{x}_{i,t}$ is the maximum production capacity, given by the product of the current productivity level times the firm's production labour force.

3.1.3. Salary and nominal wage

The nominal wage rate is determined based on the economy's average productivity:

$$w_t = w_{t-1}\left(1 + \frac{A_t - A_{t-1}}{A_{t-1}}\right) \tag{9}$$

where A_t is the economy's average productivity level. A_t is calculated as a weighted average of sectoral productivity level, with the weight being the share of sector expenditure in total expenditure, while the sectoral productivity level is computed as a weighted average of the firms' productivities within each sector weighted by their market share. In order to simplify the analysis and mitigate the effects of income distribution on consumption, each employed worker receives an equal salary of: $sal_t = w_{t-1}wj^{-1}$.

3.1.4. Mark-up and pricing

Firms' mark-up are endogenously determined through the following rule: if in the previous period, the share of sold goods over the total supply of goods $\frac{s_{i,t-1}}{x^s_{i,t-1}}$ is higher than $(1-\beta)$, firms raise their mark-ups by $\tau^{up}_{i,t}$, otherwise they reduce them by $\tau^{down}_{i,t}$. Mark-up[10] is calculated according to:

$$mk_{i,t} = \begin{cases} mk_{t-1}(1+\tau^{up}_{i,t}) & \text{if } \dfrac{s_{i,t-1}}{x^s_{i,t-1}} \geq (1-\beta) \\ mk_{t-1}(1-\tau^{down}_{i,t}) & \text{if } \dfrac{s_{i,t-1}}{x^s_{i,t-1}} < (1-\beta), \end{cases} \tag{10}$$

where $\tau^{up}_{i,t}$ and $\tau^{down}_{i,t}$ are random numbers from a Folded Normal distribution with parameters $(\mu_\tau, \sigma_{\tau(up)})$ and $(\mu_\tau, \sigma_{\tau(down)})$, respectively.

After setting mark-up, firms calculate their selling prices. Prices are set as a non-negative mark-up $mk_{i,t}$ over unit labour costs $\frac{w_{t-1}}{a_{i,t-1}}$. If in the previous period the share of sold units over the supply of goods $\frac{s_{i,t-1}}{x^s_{i,t-1}}$ is lower than a threshold ϕ, firms change their pricing strategy and apply a large price discount over their prices, so that:

$$p_{i,t} = \begin{cases} (1+mk_{i,t})\dfrac{w_{t-1}}{a_{i,t-1}} & \text{if } \dfrac{s_{i,t-1}}{x^s_{i,t-1}} \geq \phi \\ (1+mk_{i,t})\dfrac{w_{t-1}}{a_{i,t-1}}(1-RN_{i,t}) & \text{if } \dfrac{s_{i,t-1}}{x^s_{i,t-1}} < \phi, \end{cases} \tag{11}$$

where ϕ is the minimum selling target share and $RN_{i,t}$ is a random number from a Folded Normal distribution with parameters (μ_{RN}, σ_{RN}). The price discount is intended at increasing sales and so reducing excessive inventory.

3.1.5. Technological progress and productivity

Technological improvements that raise firms' productivities affect their unit labour costs and consequently their prices and profitability. We model technological progress as a stochastic process that depends on the amount of labour exclusively devoted to research $l^{rs}_{i,t}$.

The process of innovation is described in the literature as very uncertain (Aghion and Howitt, 1998; Silverberg and Verspagen, 2005). Therefore, productivity innovation in the present model is set as a two stages stochastic event. The first stage, defines "success or failure" in the discovery of a new technology. The second stage calculates by how much the firm's productivity increases (Valente and Andersen, 2002; Llerena and Lorentz, 2004).

In the first stage, a probability $\nu_{i,t}$ of success in discovering a new technology is computed based on the amount of labour devoted to R&D, that is:

$$\nu_{i,t} = 1 - e^{-\zeta_z l^{rs}_{i,t}} \tag{12}$$

where ζ_z is a coefficient that regulates the impact of labour dedicated to R&D on the probability of success in each sector. The firm succeeds when $\nu_{i,t} > o_{i,t}$, where o is a random draw from a uniform distribution on the fixed support [0, 1]. In the case of success in the first stage, the firm's productivity increases according to:

$$a_{i,t} = \max[a_{i,t-1}, FN] \tag{13}$$

where FN is a random number drawn from a Folded Normal distribution with mean equal to the previous period productivity $a_{i,t-1}$ and standard deviation equal to $\alpha_z e^{-\Phi_{i,t}}$, where $\Phi_{i,t} = (a_{i,t-1}\theta_z)^{-\eta_z}$. The parameters θ_z and η_z are fixed and set at the sector level.

Despite being an endogenous process, the rate at which firms increase their productivities is influenced by the parameters ζ_z, α_z, θ_z and η_z. The new production technique $a_{i,t}$ is available for use in the next period $t+1$.

[10] Survey data evidence summarized in Fabiani et al. (2006) show that firms in the Euro area mostly set prices according to some mark-up rules.

3.1.6. Profit, firm entry and exit

After firms and individuals have interacted in the goods market, firms assess their sales and inventories and calculate current and accumulated profits. Current profit is calculated according to:

$$\pi_{i,t} = s_{i,t}p_{i,t-1} - wb_{i,t} \tag{14}$$

where $wb_{i,t}$ is the wage bill given by: $wb_{i,t} = l_{i,t}w_{t-1}$. Accumulate profit is computed as: $\pi^{ac}_{i,t} = \pi^{ac}_{i,t-1} + \pi_{i,t}$.

Firms are deleted from the simulation if one of the two conditions occur:

1. $\pi^{ac}_{i,t-1} < wjw_{t-1}$: Accumulated profit is less than the salary of 1 (one) worker for a full working journey;
2. $ms_{i,t-1} < \xi$: The firm's market share becomes lower than a threshold ξ.

The number of firms in each sector can increase as new firms can be created through a process of fission. Firm fission is governed by a probability ρ which follows a Poisson distribution $\rho \sim \text{Poisson}(\lambda)$, where:

$$\lambda = \psi ms_{i,t} \tag{15}$$

When $\rho > 0$ fission takes place and the firm's variables are split according to a uniform distribution (a_{fiss}, b_{fiss}). The new firm is set up with the same productivity and mark-up as the mother firm. Firms have to wait a minimum of 5 (five) periods in order to be allowed to fission. The same firm can fission more than once over the simulation span.

3.2. Consumer behaviour

After firms have set their prices and paid salaries, the satiation level $sat_{z,t}$ for each sector/good is calculated. The demand side of the model is based on a non-homothetic and hierarchical demand where consumers spend their income according to given priorities as in Falkinger (1990, 1994) and Andersen (2001). The hierarchical demand establishes that, each individual will seek to purchase first a satisfactory amount of good 1 ($sat_{1,t}$), then a satisfactory amount of good 2 ($sat_{2,t}$) and finally a satisfactory amount of good 3 ($sat_{3,t}$).

This notion of consumption hierarchy is described by Pasinetti (1981, 1993). According to Pasinetti, consumption is ultimately governed by a generalised version of Engel's Law. The generalised law states that the consumption of any (basic category of) good cannot be expanded beyond its satiation level. When consumption of a good has become satiated, consumers turn their attention to the next good higher in the hierarchical ordering of goods according to their importance in consumption (Andersen, 2001). In the baseline set-up of the model, the satiation level varies across goods and time. In Cases 2 and 4, the satiations level varies only across time. As a simplification, $sat_{z,t}$ does not vary across individuals.

3.2.1. Satiation level

Empirical works on Engel curves (Moneta and Chai, 2010, 2014; Chai and Moneta, 2012, 2014) show that absolute demand satiation rarely occurs and that non-satiation is a more frequent outcome. Therefore, in order to avoid absolute satiation, the satiation level is initially set at $sat_{z,0}$ and evolves endogenously following the evolution of salaries sal_t:

$$sat_{z,t} = sat_{z,t-1}\left[1 + \epsilon_z\left(\frac{sal_{t-2} - sal_{t-1}}{sal_{t-2}}\right)\right] \tag{16}$$

where ϵ_z is the sector satiation coefficient. Differences in the parameter ϵ_z across sectors coupled with the hierarchical nature of the demand generate the income effect.

3.2.2. Income and savings

The number of individuals n^w in the economy is fixed and each individual supplies the same quantity of hours of labour wj and receives the same salary sal_t. Saving is not a conscious or planned decision, but the result of one or both of the following situations:

1. Supply shortage: the consumer is not able to buy all the desired units of one or more goods;
2. Excess wealth: the individual has more resources than needed to purchase the satiation quantity for all of the three goods.

As a simplificating assumption, individuals consume out of their wealth. A consumer's wealth available for consumption is given by:

$$wh_{h,t} = sal_t + sav_{h,t-1} \quad h = [1, 2 \ldots n^h] \tag{17}$$

where $sav_{h,t-1}$ is the worker's accumulated savings given by: $sav_{h,t} = sav_{h,t-1} + (wh_{h,t} - exp_{h,t})$ and $exp_{h,t}$ is the individual's total expenditure on all three goods.

3.2.3. Firm selection

After the satiation level and wealth have been calculated, consumption moves to the next step which is price comparison. Consumers observe the prices charged by a random subset of $\kappa_{z,h,t}$ firms in each sector. This subset is given by: $\kappa_{z,h,t} = \chi_{z,h} n^f_{z,t}$, where $n^f_{z,t}$ is the total number of firms in each sector and the parameter $\chi_{z,h}$ is calculated according to:

$$\chi_{z,h} = 1 - e^{FN^{\chi}_{z,h}} \tag{18}$$

where $FN^{\chi}_{z,h}$ is generated by a Folded Normal distribution with $(\mu_{\chi}, \sigma_{\chi})$.[11] Although the parameter $\chi_{z,h}$ is time invariant, since the number of firms in each sector $n^f_{z,t}$ may change, the actual number of firms selected $\kappa_{z,h,t}$ may vary across time. After having selected $\kappa_{z,h,t}$ firms, individuals sort them by price, from the cheapest to the most expensive.

Each consumer records the identification ($id_{z,j,t}$) of the cheapest firm from his individual list for each sector. The consumer then makes sure to include that firm in his list in the next period. This mechanism of "memory" reinforces the tendency of market concentration present in the model, as it increases the sales of firms with low prices.

3.2.4. Consumption

At each period t, three consumption cycles take place, one for each good. In the cases baseline and 3, consumers strictly follow the consumption hierarchy described earlier, that is, they only consume good 2 after having consumed good 1, and only consume good 3 after having consumed good 2. In cases 3 and 4, the hierarchy of consumption is abandoned and the sequence of consumption is randomly determined in each period t. Moreover, in cases 3 and 4 the satiation level $sat_{z,t}$ increases at the same rate in all sectors.

In each consumption cycle, consumers are randomly selected and go through the $j \in [1 : \kappa_{z,h,t}]$ firms that they have previously selected and ordered. For each firm j selected, the consumer calculates the amount of goods he wishes and can afford to purchase. Actual consumption $s^h_{z,j,h,t}$ is determined according to:

$$s^h_{z,j,h,t} = \min\left[\frac{wh_{h,t}}{p_{j,t-1}}, sat_{z,t}, x^s_{j,t}\right] \tag{19}$$

Throughout each cycle, when a consumer makes a purchase of $s^h_{z,j,h,t}$ units from a firm j, the supply of that firm $x^s_{j,t}$ and the individual's sector satiation $sat_{z,t}$ are reduced by $s^h_{z,j,h,t}$ units. In addition, the individual's wealth is reduced by $s^h_{z,j,h,t} p_{j,t-1}$. Consumers continue visiting their selected firms until one of the following three situations occur:

1. The consumer exhausts his resources;
2. The consumer purchases the satiation amount of that good;
3. The consumer visits all the $\kappa_{z,h,t}$ firms selected.

Consumers can visit each firm of their list only once. There is no guarantee that all consumers will find the desired quantity of all three goods. There is the possibility that a consumer goes though all the $j \in [1 : \kappa_{z,h,t}]$ firms and does not find a single unit available. As Eq. (19) shows, actual consumption is always bound by the satiation quantity, firms production capacity and individuals' wealth. The consumer can consume less than the satiation level $sat_{z,t}$, but never above it.

[11] The parameter $\chi_{z,h}$, varies across individuals and sectors, that is, each consumer has a distinct price searching strategy from each other, and also a distinct price searching strategy for each sector.

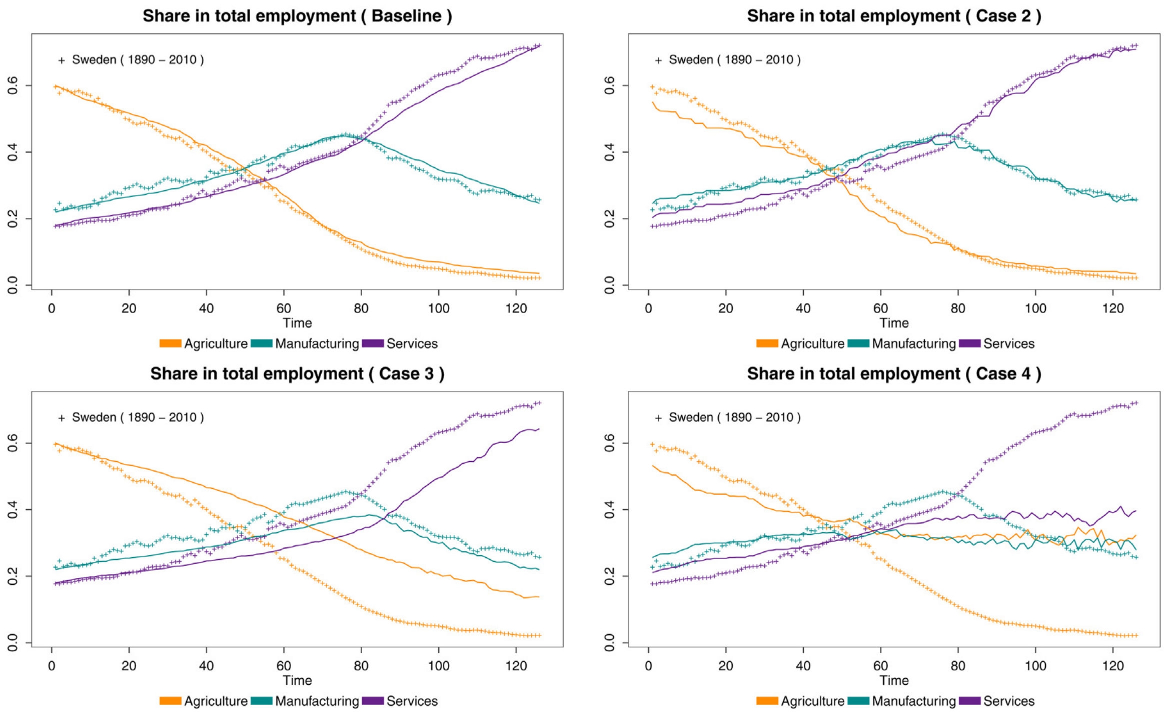

Fig. 2. Solid lines are the simulated data in the time span [3:128] of a single run. Shares of total employment for Sweden from 1890 to 2010. Data source for Sweden: Herrendorf et al. (2014).

4. Simulation and results

The parameters for the baseline scenario were calibrated as to simultaneously replicate the trajectories of the share of total employment of the three sectors of agriculture, manufacturing and services of Sweden from 1890–2010[12] (see Table A.2). The baseline scenario assumes the presence of both effects, the income and the relative prices. The other 3 scenarios were calibrated using the baseline as a reference point. Cases 2 and 3 eliminate the income effect and the relative prices effect respectively, whereas case 4 eliminates both effects.

Before we analyse the results of the Monte Carlo experiments, let us take a brief look at the different trajectories that each of the 4 scenarios is able to produced. For this initial analysis we ran 1 simulation of 130 periods for each scenario or case. Fig. 2 shows a collection of 4 plots that combines the trajectories of the share of total employment in all three sectors (agriculture, manufacturing and services) in Sweden from 1890 to 2010 with the respective simulated trajectories in the time span [3:128]. The initial sectoral shares of total employment are 0.6 for agriculture, 0.22 for manufacturing and 0.18 for services.

As expected, the trajectories of the baseline set-up (Fig. 2, top-left) are the closest to the data for Sweden in the period under analysis. In the baseline parametrisation, both effects of income and relative prices are present. Fig. 3 suggest that, in order to replicate the intended trajectories, both effects must be present in a certain way, that is, some sectoral relative conditions must be respected. In case of the relative prices effect, the sectoral productivity must evolve in a way so that the productivity in agriculture is higher than that of manufacturing which in turn is higher than that of services. In case of the income effect, the satiation point must evolve in a way that $sat_{3,t} > sat_{2,t} > sat_{1,t}$.

In case 2 (Fig. 2, top-right), the only factor determining the trajectories of employment shares are differences in average productivity growth rates across sectors. In this case, we assume that individuals do not have any particular preference or need for any of the 3 goods, and that the satiation points evolve at the same rate, that would be the equivalent of saying that consumers have homothetic preferences. Therefore, in case 2 the relative prices effect alone is inducing the reallocation of labour across sectors.

[12] We have used the data for Sweden as it is one of longest and more complete time-series available for sectoral employment share.

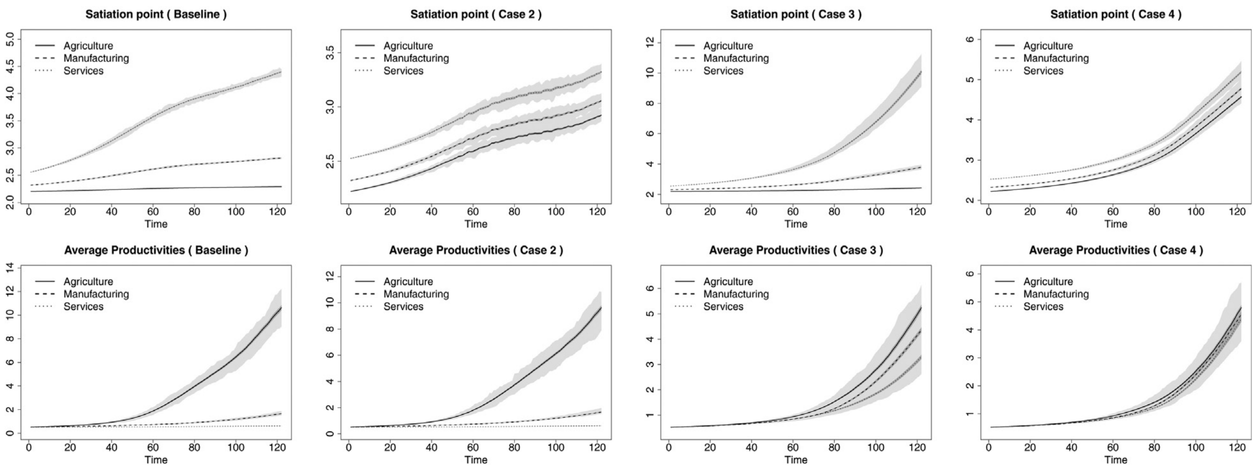

Fig. 3. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

In case 3 (Fig. 2, lower-left), we have removed the relative prices effect. As in the baseline scenario, consumers follow a hierarchical ordering in consumption, and have different income elasticities for each of the 3 goods. Case 3 shows that, even with constant relative prices, if one assumes non-unitary expenditure elasticities of demand, changes in income lead to changes in expenditure shares (see Fig. 8) and to labour reallocation across sectors.

In case 4 (Fig. 2, lower-right), all sectoral differences both in consumption and in productivity growth rates are abandoned, the only remaining differences across sectors are the initial conditions. In this case, we can observe that the sectoral employment shares tend to converge to a single level. Moreover, Fig. 3 shows that in case 4, there is no significant differences across sectors in the trajectories of the productivity growth rate and of that of the satiation point.

4.1. Monte Carlo analysis

In order to better analyse the differences in the sectoral employment share trajectories among the 4 scenarios, we have run 50 Monte Carlo simulations of 130 periods for each scenario. The differences in demand and productivity evolution amongst the 4 scenarios are depicted in Fig. 3.

All the variables at the sectoral level are calculated as weighted averages of the equivalent variables at the firm level. In simulations with ABM models, since most variables are endogenously determined it is not always possible to completely isolate the effects under analysis. In our case, we can see in Fig. 2 that in case 3 (bottom third plot from left to right) that despite having the exact same parametrization for the sectoral productivity growth rates, the sectors follow slightly different trajectories. This is because the productivity level is being affected by the income effect, that is, by the hierarchical and non-homothetic aspects of the demand.

Although apparently unexpected, this behaviour seems to be in line with the findings of Krüger (2008) presented in the introduction. According to him, in all the theories reviewed, technological progress is the driver of structural change, but it is frequently the demand side that is crucial for determining which industries grow faster. We see in Fig. 2, that the effect of technological progress is stronger than that of demand over the employment share trajectories. In addition, case 3 shows that due to differences in the demand side, the agriculture sector grows slightly faster than the other sectors, despite the fact that in this scenario all sectors have the same parametrization regarding productivity growth rates.

If we eliminate both effects (Case 4), we can observe that the differences in the trajectories of the sectoral average productivities disappears. Interesting to note that in case 2, the trajectories of satiation point are not influenced by the differences in sectoral productivity growth rates. This happens because the evolution of the satiation point is only affected by the nominal wage, and thus by the economy’s average productivity.

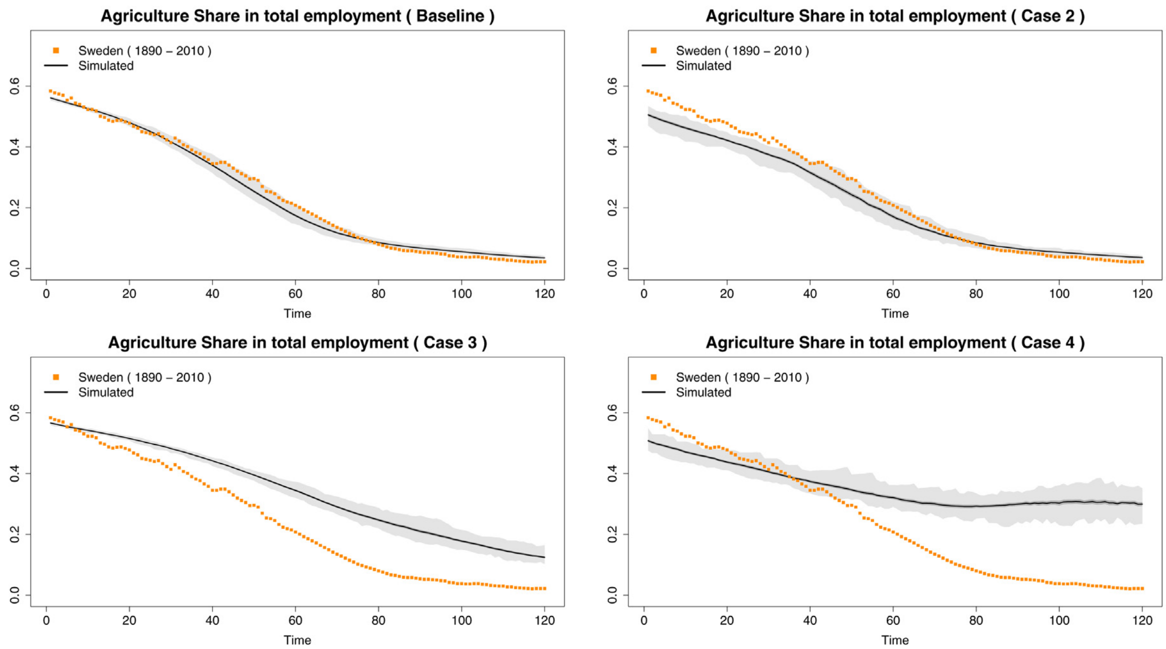

Fig. 4. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

4.1.1. Employment share in agriculture

In all 4 scenarios, the share of total employment in agriculture tends to fall over time. However, the Monte Carlo simulations confirm what Fig. 2 shows, that the speed with which the employment share in agriculture falls varies greatly amongst the 4 scenarios.

Fig. 4 suggests that changes in the demand structure alone produce only minor effects on the trajectory of the agriculture employment share while, changes in the sectors productivity growth rates, tend to produce major effects in its trajectory. This result is not a surprise, as empirical and theoretical studies suggest the existence of a strong positive relationship between productivity in the agricultural sector and decreases in the employment share in that sector (Caselli, 2005; Herrendorf et al., 2014). Caselli (2005) also finds that poverty and the share of the working population employed in agriculture are positively related. Hence, increases in GDP per capita are correlated with decreases in the employment share in agriculture. The same result is reported in Gollin et al. (2002), which shows that growth in agricultural productivity is quantitatively important in explaining income per capita growth.

The simulation indicates that the income and the relative prices effects are both relevant in explaining the falling trend of employment share in agriculture in developed countries. The relative prices effect seems to be stronger than the income effect, as when we remove that effect in case 3 (Fig. 4 bottom-left), there is a greater change in the agriculture employment share trajectory than that of case 2 (Fig. 4 top-right) when we remove the income effect. Case 4 (Fig. 4 bottom-right) shows that when both effects are eliminated, the agriculture employment share trajectory is becomes very distant from the desired one.

4.1.2. Employment share in manufacturing

Regarding the manufacturing sector, Herrendorf et al. (2014) found that employment share tend to follow a hump shape, increasing for lower levels of development and decreasing for higher levels of development.

Looking at Fig. 5 we can observe a hump shape in cases baseline, 2 and 3. The baseline set-up (Fig. 5 top-left), by construction is the closest to the real data. Case 2 (Fig. 5 top-right) produces a hump shaped trajectory that peaks at a lower level than both the baseline and the Sweden data. Case 3 (Fig. 5 bottom-left), despite equal productivity parametrization across sectors, the model still produces a hump shaped trajectory. Case 4 (Fig. 5 bottom-right), shows that, once we abandon both effects, the hump shaped trajectory described in the literature disappears.

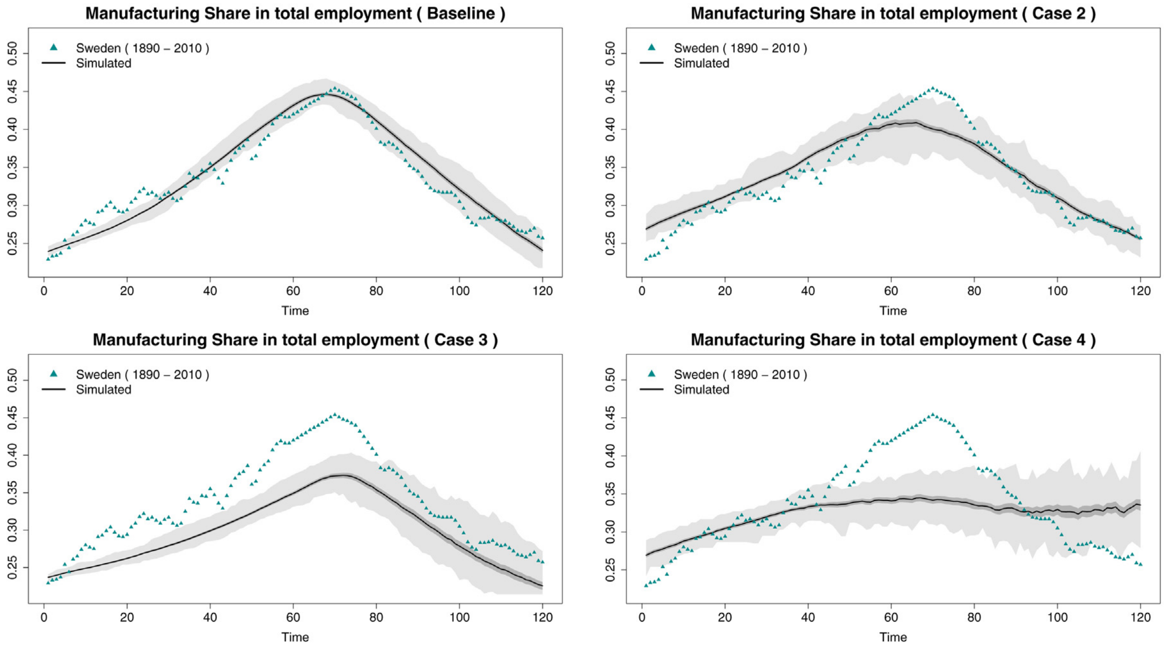

Fig. 5. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

The results suggest that both effects are relevant in explaining the hump shaped trajectory of the employment share in the manufacturing. As for the employment share in agriculture, the relative prices effect seems to be stronger than the income effect.

4.1.3. Employment share in services

One of the striking features of developed economies is the large size of their service sector. According to Fisher (1935) and Clark (1940), the income-elasticity for services (which were considered luxuries) is greater than one. Therefore, as income-per-capita grows, the share of goods in overall demand will decline and that of services will rise. Because services rank higher in the hierarchy of needs, individuals allocate more resources to services as their incomes grow. Consequently, wealthier countries have a higher share of service demand and of service employment. We can assume that today's share of services employment is higher than in the past because societies demand more services (Schettkat and Yocarini, 2006).

Regarding the services sector share in total employment, our simulations are in line with the literature. Fig. 6 shows that, for the services share in total employment, as for the other two sectors, both effects of income and relative prices appear to be relevant in order to replicate the trajectory observed in developed countries. In case 2 (Fig. 6 top-right), the trajectory of the employment share is not significantly altered in comparison with the baseline scenario (Fig. 6 top-left). As for case 3 (Fig. 6 bottom-left), we see greater departure from the reference trajectory. Once more we observe a dominance of the relative prices effect over the income effect. When both effects are abandoned in case 4 (Fig. 6 bottom-right), the trajectory of the services employment share departs completely from that of the baseline's.

The empirical literature has shown that the productivity in the service sector is in general low. Due to low productivity, the services sector tends to absorb most of the labour force as economies develop. Already in 1949 Fourastié and Siegfried (1949) saw in low productivity growth rate of services the hope for employment. Fig. 7 shows that the higher the productivity growth rate in the services sector, the higher the unemployment rate in the economy. When the productivity in the services sector is low, as the economy develops that sector tends to absorb most of the workforce.

Lastly, the results show that, when simulating long run variables, even minor changes in key parameters have major impact on the intended trajectories. Our results provide some (non-exhaustive) evidence to suggest that the effects of income and relative prices are complementary in generating the process of structural. Moreover, in order to replicate the long-run trajectory of sector employment share observed in developed countries, sectoral productivity must evolve

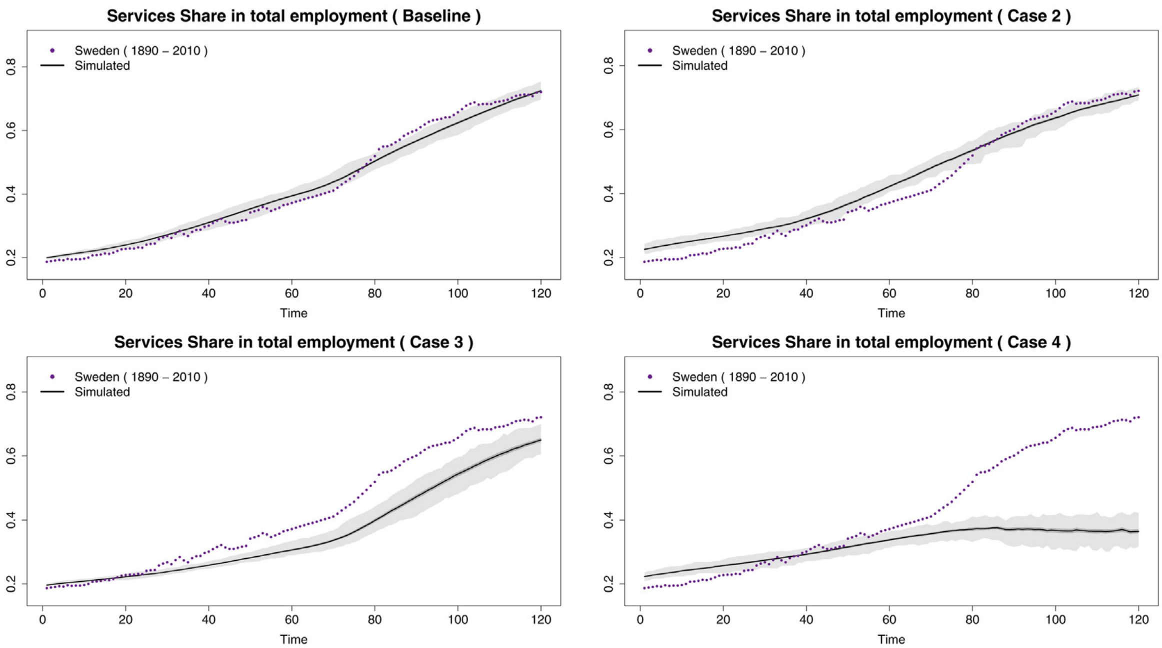

Fig. 6. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

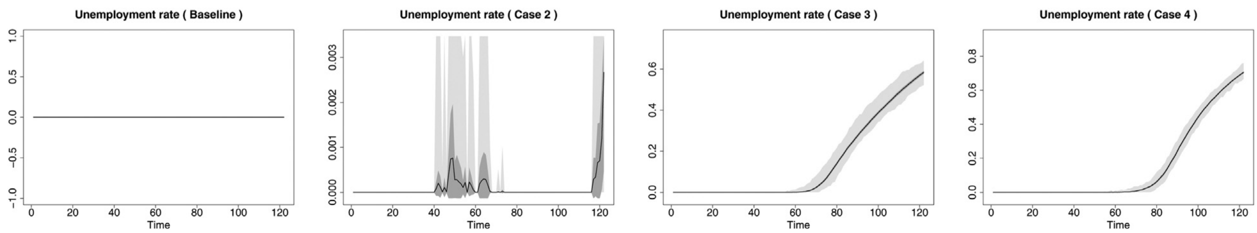

Fig. 7. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

in a way so that the productivity in agriculture is higher than that of manufacturing which in turn is higher than that of services and the satiation point must evolve in a way that $sat_{3,t} > sat_{2,t} > sat_{1,t}$.

4.1.4. *Other sectoral and aggregate variables*

There are basically three measures of economic activity at the sectoral level: (1) employment shares; (2) value added shares; (3) final consumption expenditure shares. Employment shares are typically calculated either by using workers or hours worked by sector. Sector value added shares and final consumption expenditure shares can be expressed in current prices (nominal shares) or in constant prices (real shares). Fig. 8 shows the evolution of the employment, value added and nominal final consumption expenditure shares. We can observe that all three measures of economic activity at the sectoral level follow very closely within their respective cases.

The model was built based on a demand driven economy, where firms increase production only if they expect increases in demand. Fig. 9 shows the evolution of sectoral production and consumption. As expected, both variables evolve very closely. In cases baseline, 2 and 3, due to the income and/or relative prices effect, there is a divergent trend amongst the sectors. In case 4, since there is no forces favouring any sector, both sectoral production and consumption tend to converge to a single level.

The literature on economic growth has long agreed that the rate of productivity growth is one of the primary determinant of an economy's rate of long-term economic growth and higher wages. Fig. 10 shows that as labour is shifted towards the service sector, the average productivity and the real GDP growth rate falls. This happens because the productivity in the services sector is lower than that of the other two sectors.

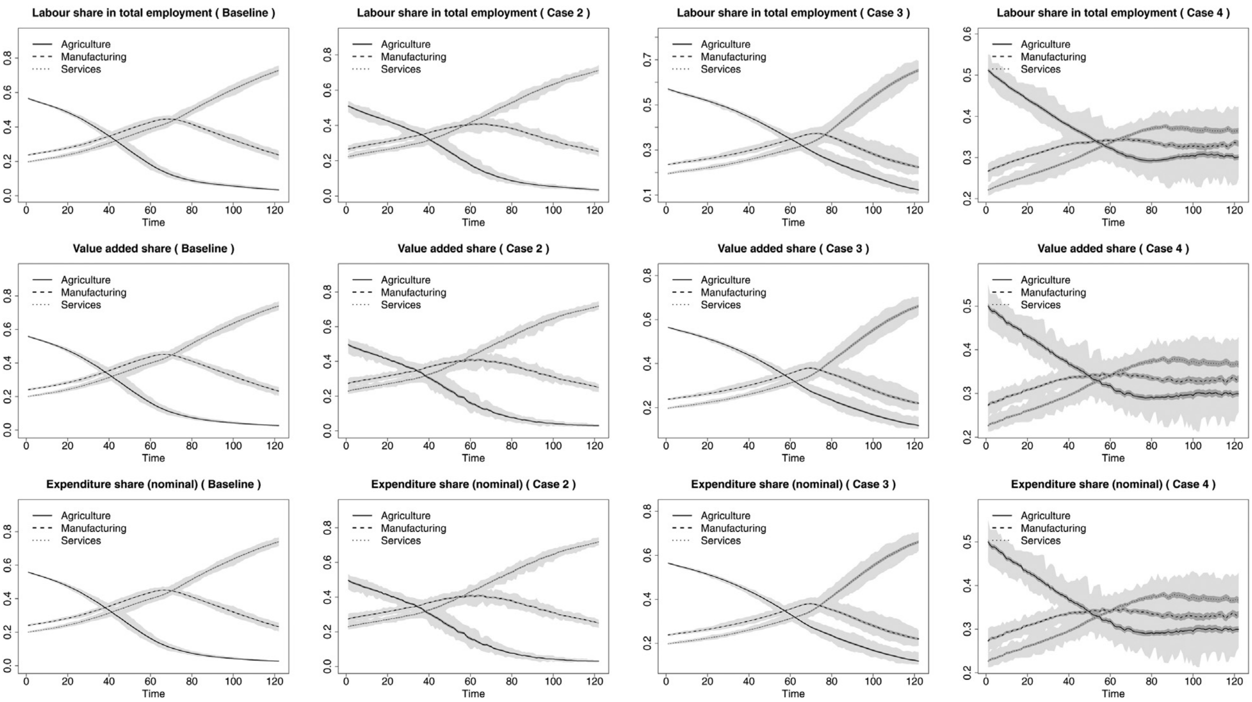

Fig. 8. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

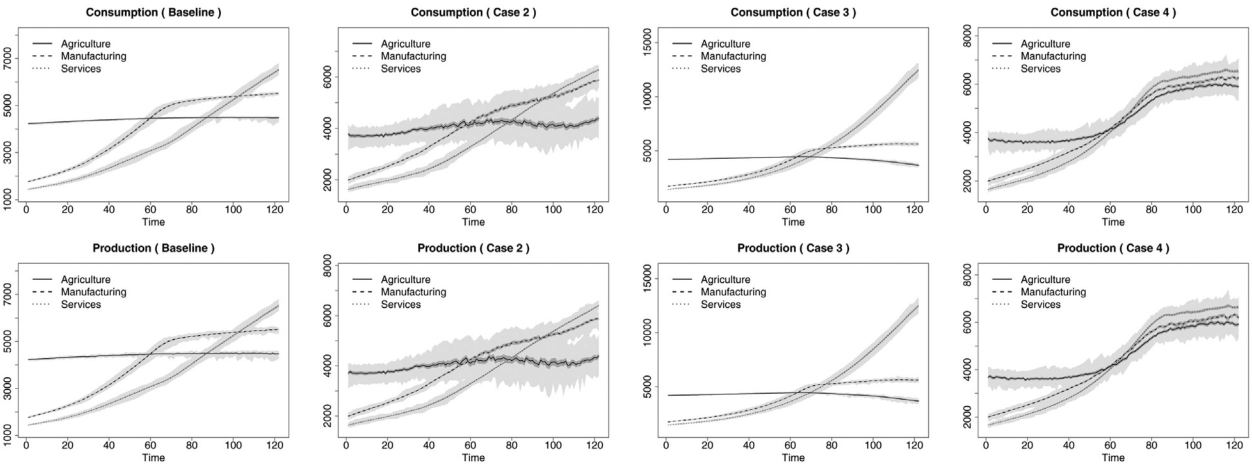

Fig. 9. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

Regarding real GDP per capita, Fig. 10 shows that it is higher in cases 3 and 4 than in cases baseline and 2. This is so due to the fact that the rate of productivity growth in the services sector in those cases are higher than those in cases baseline and 2.

The trajectories of the average price are within what was expected, given that productivity plays a major role in determining the firms' unitary costs. Fig. 11 reports the evolution of average prices for all scenarios. For the baseline and case 2, where sector productivity growth rates are parametrised to be distinct, we observe that sectoral average prices follow a similar path. In cases 3 and 4, but specially in case 4 where there is neither income nor relative prices effect, there is a tendency of convergence among the trajectories. In addition, we observe a much larger volatility in case 4 as it can be seen by the broader confidence bands in grey. Despite the average price trajectories in cases baseline

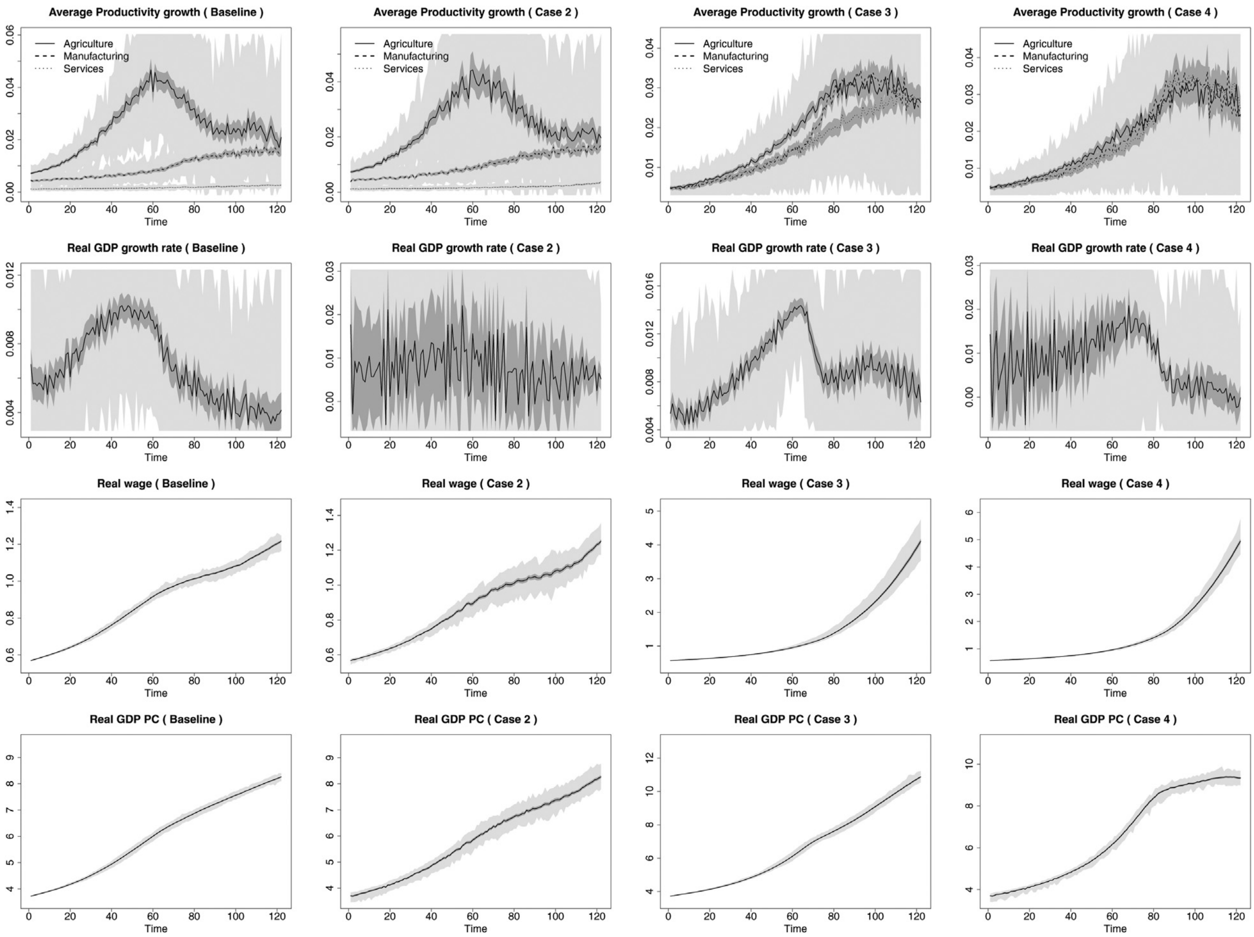

Fig. 10. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

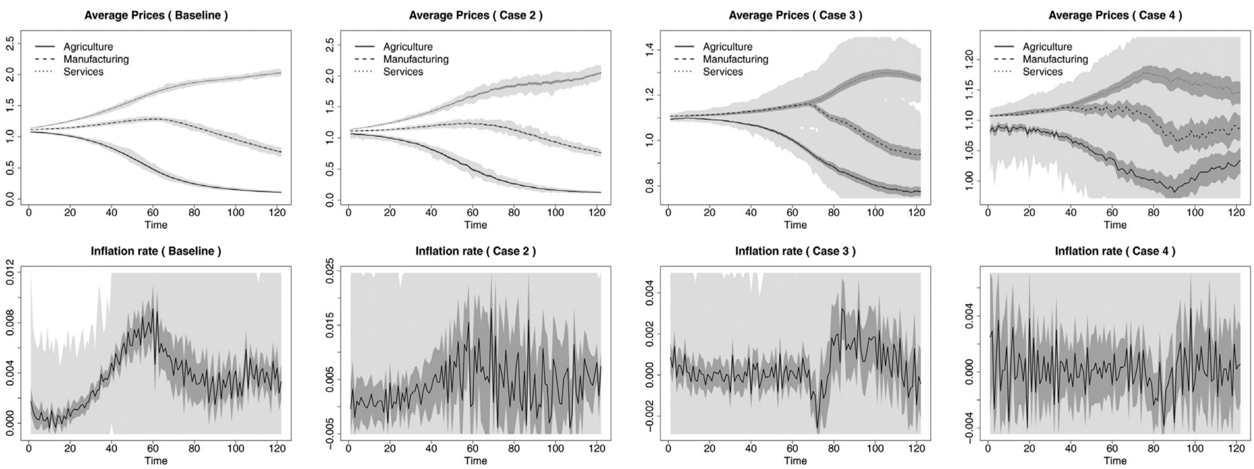

Fig. 11. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

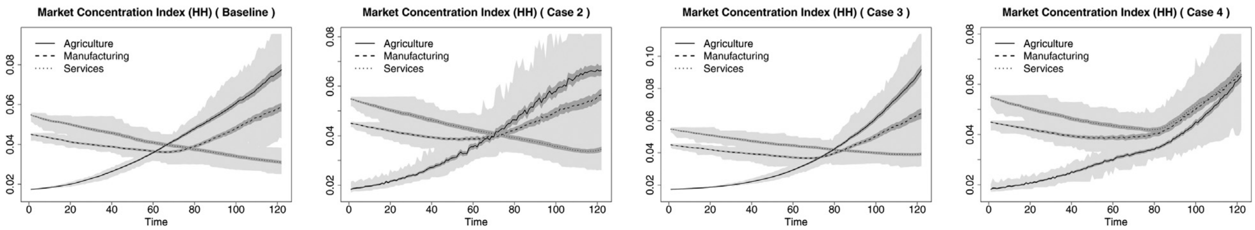

Fig. 12. Simulated series are averages of 50 monte carlo runs. 95% confidence band in gray, min/max values in light gray.

and 2 being similar, their inflation rates are quite distinct. Inflation in case 2 is not only more volatile but it is also higher on average.

Despite the fact that firms, within each sector, are perfectly homogeneous at the beginning of the simulation, heterogeneity emerges as a consequence of the inherent stochasticity that affects both firms and consumers, and of the cumulative effects that arise from innovation and competition among firms.

The innovation, the consumers' searching scheme and memory mechanism affect the evolution of market shares. From an initial situation in which firms' market shares within sectors are all equal, market concentration within each sector follow different paths depending on the sector and on the experiment as we can see in Fig. 12. We can observe that the market concentration in manufacturing initially decreases and then increases in all 4 scenarios. The market concentration in agriculture increases in all 4 scenarios, though at different rates. Finally, the market concentration in services falls in cases baseline, 2 and 3 and increases in case 4. In this case, as there is neither income nor relative prices effect, the market concentration index follows a convergent and increasing trend across the three sectors.

A set of additional relative metrics is presented in Table B.3, which uses the baseline case as a point of comparison. Most of the reported variables are statistically different in cases 2, 3 and 4 in comparison with the baseline. The exception is the number of firms, which shows no significant statistical difference across the experiments. Table B.4 in the appendix reports the averages, standard deviation, maximum and minimum values for selected variables in all 4 scenarios.

5. Concluding remark

When one looks at the data, one sees that, on average poor countries have lower labour productivity and a larger share of employment in agriculture. Historically, the process of growth in developed economies has been accompanied by the shift of labour out of agricultural and into manufacturing and services. According to the literature, the process of structural change can be explained by a series of causal factors that include, but are not limited to, differences in income elasticities and productivity growth rates across sectors. The model developed in the present article was intended at theoretically replicating the dynamics of structural change where labour is reallocated across the three macro-sectors of agriculture, manufacturing and services.

By using the data of Sweden as a reference point, we have calibrated the model's parameters so that the artificial sectoral employment share trajectories generated by the model would match those of the real data. The model provide some (non-exhaustive) evidence to suggest that the effects of income and relative prices are complementary in generating a process of structural. We do not claim that the two effects analysed here are the true or the only determining factors in the process of structural change. However, we can conclude that, if both effects are present and we assume that the sectoral productivity evolves in a way that agriculture > manufacturing > services and the satiation point evolves in a way that services > manufacturing > agriculture, it possible to theoretically yield structural changes in an agent-based model focusing only on first principles such as tastes and technologies.

Our model can be extended in several directions. However, three extensions are most promising. First, while the model assumes a fixed number of goods, the introduction of a process of product creation within each macro-sector would enrich the analysis by allowing the analysis of the reallocation of labour not only across the three macro-sectors of agriculture, manufacturing and services, but also within them. Second, while our analysis has assumed a uniform income distribution, the introduction of heterogeneous labour where workers receive different wages is potentially interesting, as the existence of rich and poor households with different consumption bundles would open up a new channel through which income inequality could affect growth and structural change. Third, although our analysis focused on a closed economy, Araujo and Teixeira (2004), Araujo and Lima (2007) demonstrate that international trade plays an important role in generating structural change, thus the next natural step would be to consider how hierarchic preferences and sectoral differential productivities would affect the processes of structural change and growth in a world with different product specializations.

Appendix A. Parameters values and initial set-up

Tables A.1 and A.2

Table A.1
Model parameters and initial conditions.

Symbol	Description	Equation	Value
Industrial dynamics			
$(\mu_\tau, \sigma_{\tau(up)})$	Folded Normal Distribution parameters (Mark-up)	(10)	(0,0.001)
$(\mu_\tau, \sigma_{\tau(down)})$	Folded Normal Distribution parameters (Mark-up)	(10)	(0,0.01)
(μ_{RN}, σ_{RN})	Folded Normal Distribution parameters (Price)	(11)	(0.3,0.1)
ϕ	Minimum selling target share	(11)	0.7
β	Desired excess production share	(2)	0.1
ω	Adaptive expectations parameter	(1)	0.25
δ	Maximum labour firing share	–	0.2
γ	Maximum labour share to R&D	(5)	0.1
ξ	Minimum market share	–	0.0001
(a_{fiss}, b_{fiss})	Fission uniform distribution parameters	–	(0.2,0.45)
ψ	Probability of firm fission coefficient	(15)	0.2
Labour market and demand			
n^h	Number of Workers/Consumers	–	2000
wj	Working journey	–	8 (h)
ϵ	Demand coefficient	(16)	See Table A.2
(μ_χ, σ_χ)	Folded Normal Distribution parameters (χ)	(18)	(0,0.5)
Technology			
ζ	Coefficient of success in innovation	(12)	See Table A.2
θ	Innovation coefficient	(13)	See Table A.2
α	Innovation coefficient	(13)	See Table A.2
η	Innovation coefficient	(13)	1.01
Initial conditions			
N_0^f	Total initial number of firms	–	100
$n_{z,0}^f$	Sector initial number of firms	–	See Table A.2
$ls_{1,0}$	Initial agriculture labour share	–	0.6
$ls_{2,0}$	Initial manufacturing labour share	–	0.22
$ls_{3,0}$	Initial services labour share	–	0.18
w_0	Initial wage rate	–	0.5 (MU/h)
y_0	Initial income per capita	–	4
u_0	Initial unemployment	–	0
p_0	Initial price	–	1.11 (MU)
a_0	Initial labour productivity	–	0.5(units/h)
mk_0	Initial mark-up	–	0.11
uc_0	Initial unit Cost	–	1.0 (MU)
rds_0	Initial labour share to R&D	–	0.1
π_0^{acc}	Initial endowment per firm	–	800 (MU)
l_0	Initial labour force per firm	–	20 (workers)
sat_0^z	Initial desired demand	–	See Table A.2

Table A.2
Sector and experiment value specific parameters and initial conditions.

Symbol	Description	Eq.	Baseline			Case 2			Case 3			Case 4		
			Agri	Manu	Serv	Agri	Manu	Serv	Agri	Manu	Serv	Agri	Manu	Serv
$n^f_{z,0}$	Initial number of firms	–	60	22	18	60	22	18	60	22	18	60	22	18
sat^z_0	Initial desired demand	(16)	2.2	2.3	2.5	2.2	2.3	2.5	2.2	2.3	2.5	2.2	2.3	2.5
θ	Innovation coefficient	(13)	0.44	0.58	0.35	0.44	0.58	0.35	0.456	0.456	0.456	0.456	0.456	0.456
α	Innovation coefficient	(13)	0.72	0.16	0.45	0.72	0.16	0.45	0.44	0.44	0.44	0.44	0.44	0.44
ζ	Coefficient of success in innovation	(12)	0.4	0.41	0.43	0.4	0.41	0.43	0.413	0.413	0.413	0.413	0.413	0.413
ϵ	Demand coefficient	(16)	0.05	0.25	0.7	0.33	0.33	0.33	0.05	0.25	0.7	0.33	0.33	0.33

Appendix B. Experiments comparison table

Tables B.3 and B.4

Table B.3
[A] Agriculture, [M] Manufacturing, [S] Services. Experiments: Performance comparison among the 3 cases (Baseline, Case 2 and Case 3). Averages for 50 MC runs. p-Value for a two-means t test, H_0: no difference between scenarios.

	Baseline	Case 2		Case 3		Case 4	
		Ratio	p-Value	Ratio	p-Value	Ratio	p-Value
Real GDP PC	5.972	0.981	0.000	1.103	0.000	1.104	0.000
Nominal GDP PC	6.556	0.988	0.000	1.120	0.000	1.122	0.000
Real GDP growth rate	0.007	1.127	0.000	1.344	0.000	1.212	0.000
Average productivity	0.828	0.988	0.000	1.562	0.000	1.695	0.000
Average productivity growth	0.006	1.078	0.000	2.556	0.000	2.811	0.000
Inflation rate	0.004	1.091	0.000	0.092	0.000	0.025	0.000
Nominal Wage	0.824	0.988	0.000	1.563	0.000	1.696	0.000
Total nominal inventory	245.476	0.858	0.000	1.402	0.000	1.209	0.000
Productivity growth (A)	0.025	0.967	0.000	0.767	0.000	0.738	0.000
Productivity growth (M)	0.010	1.006	0.522	1.841	0.000	1.879	0.000
Productivity growth (S)	0.002	1.038	0.000	8.957	0.000	10.394	0.000
Average price (A)	0.538	1.014	0.014	1.784	0.000	1.933	0.000
Average price (M)	1.112	0.979	0.000	0.975	0.000	0.991	0.078
Average price (S)	1.642	0.987	0.000	0.721	0.000	0.696	0.000
Satiation point (A)	2.252	1.143	0.000	1.014	0.000	1.297	0.000
Satiation point (M)	2.590	1.040	0.000	1.081	0.000	1.179	0.000
Satiation point (S)	3.514	0.833	0.000	1.308	0.000	0.945	0.000
Effective demand PC (A)	2.210	0.917	0.000	0.964	0.000	1.041	0.000
Effective demand PC (M)	2.033	0.998	0.355	0.984	0.000	1.063	0.000
Effective demand PC (S)	1.730	1.043	0.000	1.421	0.000	1.231	0.000
Sectoral Nominal GDP PC (A)	1.175	0.918	0.000	1.745	0.000	2.025	0.000
Sectoral Nominal GDP PC (M)	2.218	0.973	0.000	0.964	0.000	1.070	0.000
Sectoral Nominal GDP PC (S)	3.057	1.024	0.000	0.988	0.066	0.802	0.000
Number of firms (A)	49.562	0.987	0.012	1.027	0.000	1.053	0.000
Number of firms (M)	34.965	0.979	0.148	0.977	0.118	0.980	0.183
Number of firms (S)	31.271	0.954	0.006	0.950	0.005	0.958	0.007
Average markup (A)	0.114	0.994	0.000	1.004	0.000	0.999	0.244
Average markup (M)	0.116	0.999	0.006	1.001	0.001	1.000	0.572
Average markup (S)	0.116	1.001	0.000	1.000	0.917	1.000	0.273
Industry concentration index HH (A)	0.040	0.976	0.074	0.958	0.001	0.817	0.000
Industry concentration index HH (M)	0.043	1.026	0.040	1.030	0.013	1.037	0.006
Industry concentration index HH (S)	0.041	1.031	0.009	1.085	0.000	1.176	0.000

Table B.4
Numbers in brackets indicate the experiment number: [1] Baseline, [2] Case 2, [3] Case 3, [4] Case 4. MC runs = 50/period = 4-126.

	Avg[1]	SD[1]	Min[1]	Max[1]	Avg[2]	SD[2]	Min[2]	Max[2]	Avg[3]	SD[3]	Min[3]	Max[3]	Avg[4]	SD[4]	Min[4]	Max[4]
Real GDP PC	5.972	0.041	5.862	6.064	5.858	0.077	5.629	5.991	6.589	0.074	6.423	6.774	6.592	0.063	6.410	6.722
Nominal GDP PC	6.556	0.043	6.436	6.639	6.477	0.085	6.231	6.635	7.345	0.082	7.160	7.544	7.358	0.068	7.160	7.506
Real GDP growth rate	0.007	0.000	0.006	0.007	0.007	0.000	0.007	0.008	0.009	0.000	0.009	0.009	0.008	0.000	0.007	0.009
Average productivity	0.828	0.006	0.813	0.839	0.819	0.011	0.788	0.838	1.294	0.047	1.195	1.460	1.404	0.048	1.315	1.508
Average productivity growth	0.006	0.000	0.006	0.007	0.007	0.000	0.006	0.007	0.016	0.001	0.015	0.018	0.018	0.000	0.017	0.019
Inflation rate	0.004	0.000	0.003	0.004	0.004	0.000	0.003	0.004	0.000	0.000	0.000	0.001	0.000	0.000	-0.000	0.000
Nominal Wage	0.824	0.005	0.809	0.835	0.815	0.011	0.784	0.835	1.288	0.047	1.190	1.454	1.398	0.048	1.311	1.499
Total nominal inventory	245.476	6.676	229.940	260.933	210.525	8.370	190.717	230.648	344.076	13.708	307.044	373.777	296.718	13.782	265.963	329.152
Productivity growth (A)	0.025	0.001	0.024	0.026	0.024	0.001	0.023	0.025	0.019	0.001	0.017	0.021	0.018	0.001	0.017	0.020
Productivity growth (M)	0.010	0.000	0.009	0.011	0.010	0.000	0.009	0.011	0.018	0.001	0.016	0.019	0.018	0.001	0.017	0.020
Productivity growth (S)	0.002	0.000	0.002	0.002	0.002	0.000	0.002	0.002	0.015	0.001	0.013	0.017	0.018	0.001	0.016	0.020
Average price (A)	0.538	0.015	0.508	0.578	0.545	0.015	0.508	0.580	0.960	0.033	0.893	1.060	1.040	0.036	0.936	1.111
Average price (M)	1.112	0.016	1.074	1.139	1.089	0.017	1.053	1.125	1.084	0.038	1.010	1.172	1.102	0.036	1.039	1.186
Average price (S)	1.642	0.013	1.612	1.672	1.620	0.019	1.567	1.655	1.184	0.035	1.105	1.290	1.143	0.027	1.086	1.201
Satiation point (A)	2.252	0.001	2.250	2.254	2.575	0.011	2.540	2.598	2.284	0.003	2.278	2.294	2.921	0.024	2.874	2.971
Satiation point (M)	2.590	0.004	2.578	2.598	2.692	0.012	2.656	2.716	2.799	0.018	2.760	2.865	3.054	0.026	3.005	3.106
Satiation point (S)	3.514	0.016	3.470	3.546	2.926	0.013	2.887	2.952	4.595	0.103	4.378	4.962	3.319	0.028	3.266	3.377
Effective demand PC (A)	2.210	0.004	2.201	2.217	2.027	0.067	1.876	2.190	2.130	0.009	2.100	2.144	2.300	0.038	2.208	2.363
Effective demand PC (M)	2.033	0.019	1.981	2.071	2.028	0.033	1.957	2.109	2.001	0.025	1.949	2.056	2.161	0.031	2.110	2.216
Effective demand PC (S)	1.730	0.027	1.674	1.809	1.804	0.027	1.743	1.866	2.458	0.072	2.294	2.610	2.130	0.031	2.046	2.190
Sectoral Nominal GDP PC (A)	1.175	0.032	1.112	1.260	1.078	0.044	0.975	1.174	2.050	0.066	1.910	2.250	2.379	0.102	2.148	2.593
Sectoral Nominal GDP PC (M)	2.218	0.037	2.141	2.300	2.158	0.042	2.073	2.241	2.139	0.087	1.975	2.353	2.373	0.091	2.199	2.557
Sectoral Nominal GDP PC (S)	3.057	0.068	2.899	3.208	3.129	0.063	2.958	3.268	3.021	0.117	2.782	3.341	2.453	0.082	2.293	2.617
Number of firms (A)	49.562	1.104	47.574	52.721	48.900	1.458	45.508	51.967	50.876	1.079	48.336	53.164	52.173	1.188	49.541	55.098
Number of firms (M)	34.965	2.382	29.598	40.303	34.242	2.578	26.795	39.172	34.160	2.716	28.533	41.385	34.248	2.937	27.975	40.393
Number of firms (S)	31.271	2.570	25.475	37.541	29.836	2.497	24.746	36.516	29.722	2.819	24.516	36.680	29.949	2.184	25.844	34.156
Average markup (A)	0.114	0.000	0.113	0.114	0.113	0.000	0.112	0.114	0.114	0.000	0.114	0.114	0.114	0.000	0.113	0.115
Average markup (M)	0.116	0.000	0.115	0.116	0.115	0.000	0.115	0.116	0.116	0.000	0.115	0.116	0.116	0.000	0.115	0.116
Average markup (S)	0.116	0.000	0.116	0.116	0.116	0.000	0.116	0.116	0.116	0.000	0.116	0.116	0.116	0.000	0.115	0.116
Industry concentration index HH (A)	0.040	0.002	0.035	0.046	0.039	0.003	0.035	0.049	0.038	0.002	0.033	0.045	0.033	0.002	0.029	0.039
Industry concentration index HH (M)	0.043	0.002	0.037	0.049	0.044	0.003	0.038	0.052	0.044	0.003	0.037	0.049	0.044	0.003	0.037	0.053
Industry concentration index HH (S)	0.041	0.002	0.036	0.047	0.043	0.003	0.036	0.048	0.045	0.002	0.041	0.049	0.049	0.003	0.044	0.054

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